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THE ASSESSMENT OF THE SOUND INSULATION REQUIREMENTS FOR A LARGE BROADCASTING STUDIO, USING A SCALE MODEL:

Practical details

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Summary

The techniques used in carrying out the assessment of relative levels of road traffic noise at the surfaces of a large building, using a scale model, are described. The results of such an assessment on a 100:1 scale model of a proposed new building at the BBC's Television Centre are considered. The choice of a type of wall design which minimises the constructional costs of the building, whilst maintaining adequate isolation from road traffic noise, is outlined.

Issued under the Authority of

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Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

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1. INTRODUCTION

The facilites provided as part of the development currently taking place at the BBC's Television Centre in West London will include a large multipurpose television studio (Studio 9), with overall floor dimensions of about 31 metres by 26 metres, and having permanent audience seating. A particular feature is a "fly tower" about 24 metres high extending over the whole stage area of the studio (Fig. 1), so that scenery changes can be made during the course of a production to give artistic continuity. At the time that the work described in this Report was carried out the design of the building was such that the fly tower would have been taller than the main part of the building, at least on some of its elevations. This would have exposed the upper part of the walls of Studio 9 (shown shaded in Fig. 1) to external ambient noise, particularly from traffic passing along the road (Wood Lane) bordering the Eastern boundary of the site. Fig. 2 shows an architect's sketch (prepared by the BBC's Architectural and Civil Engineering Department) of Television Centre, with the new development (as then envisaged) on the right-hand side of the figure. The position of the fly-tower of Studio 9 in the structure is indicated diagrammatically by heavy full and dotted lines, and the position of the ceiling slab is also shown so that the exposed North-East faces of the studio and its roof void may be distinguished. The North-West faces are also exposed but are not visible in Fig. 2.

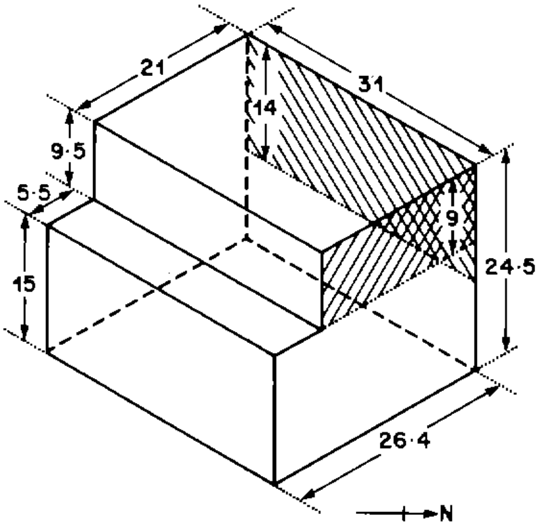

Fig. 1 - Outline of Studio 9, Television Centre.
Dimensions are in metres.

▨ North-East wall
▧ North-West wall
} Areas exposed to traffic noise.

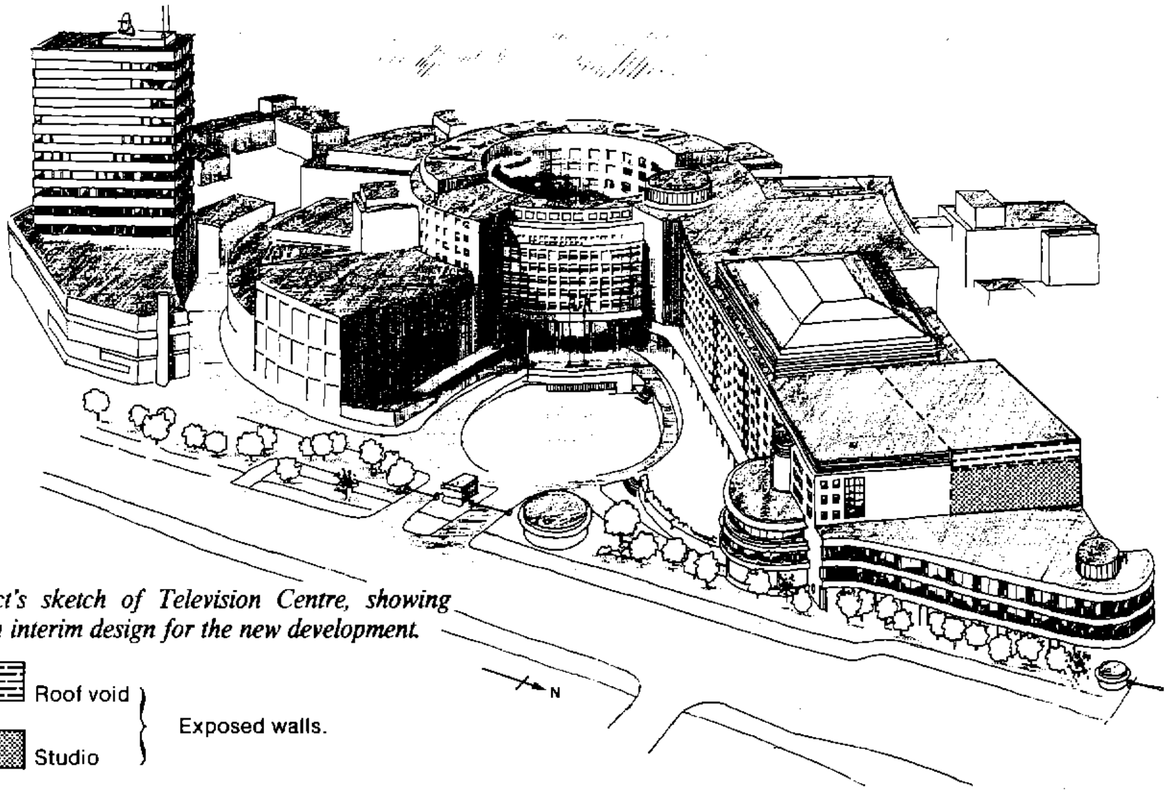

Fig. 2 - Architect's sketch of Television Centre, showing (lower right) an interim design for the new development.

☰ Roof void
▒ Studio
} Exposed walls.

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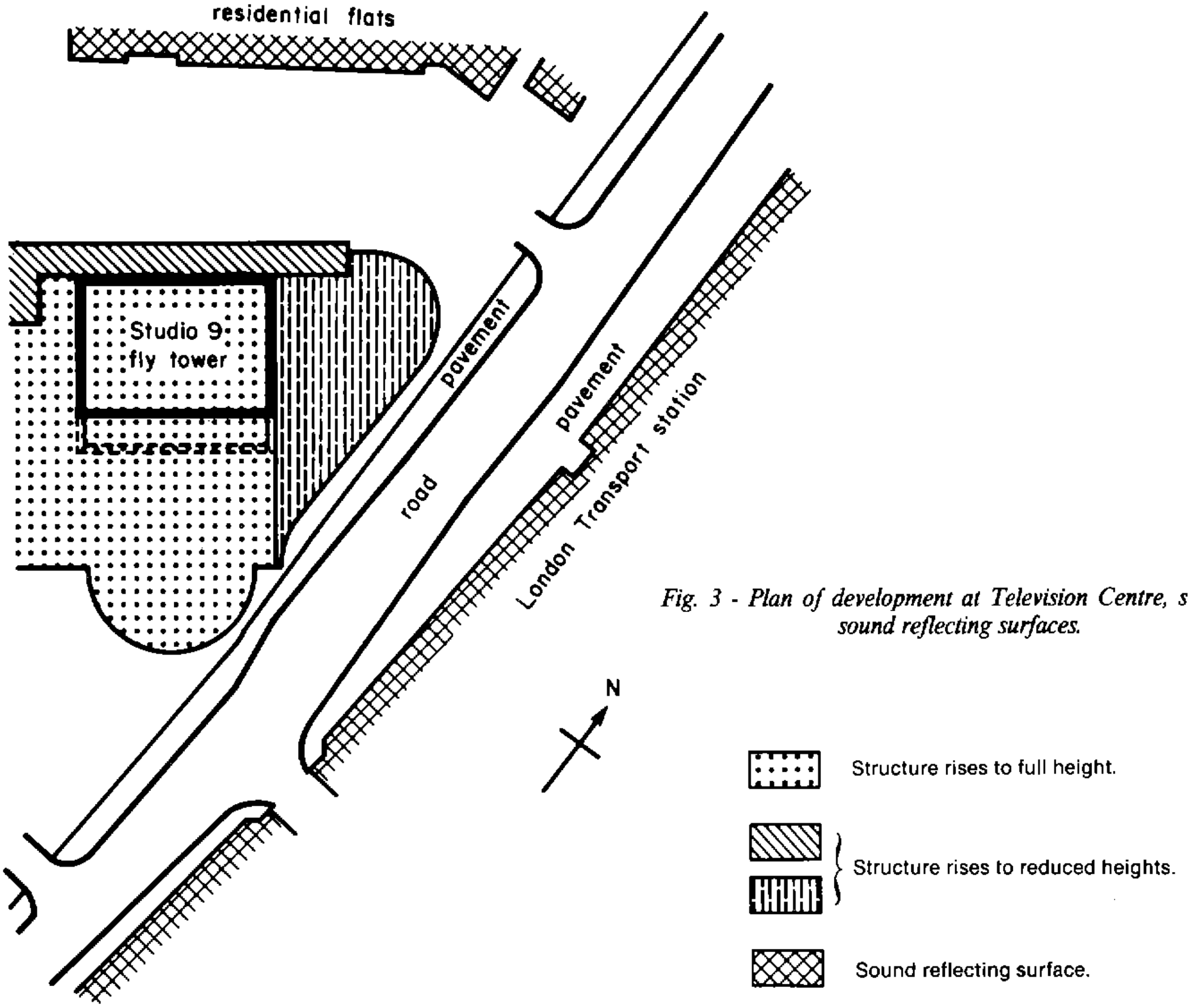
residential flats
Studio 9 fly tower
pavement
pavement
road
London Transport station
N
▦ Structure rises to full height.
▧ ▥ Structure rises to reduced heights.
▩ Sound reflecting surface.

Fig. 3 - Plan of development at Television Centre, showing sound reflecting surfaces.

Fig. 3 shows a plan of the proposed building, together with detail of the road and pavement layouts and the portions of neighbouring buildings that are liable to reflect traffic noise back to the exposed Studio 9 wall surfaces.

In order to meet the background noise level criterion inside Studio 9, the walls exposed to traffic noise must provide adequate attenuation of this noise. Data has been published[1] by the Engineering Division of the BBC which relates the sound pressure level difference across a partition to the structure of the partition itself. This data has been used in the present work. Measurements of road traffic noise made (by Sound Research Laboratories Ltd) in 1983 indicated that there was a strong low-frequency component, particularly in the third-octave band centered on 63 Hz. Structures that give high sound attenuation at low frequencies are inevitably massive in construction and may consist of two or even three leaves with relatively large voids between them (see Section 4.2). In the present case the large size of Studio 9 adds to the problem, as it is structurally complicated as well as expensive to construct a stable multi-leaf partition to the required height: it must be remembered that the leaves making up the partition have to be acoustically isolated from each other, which makes supporting them (particularly the centre leaf in a three-leaf structure) difficult. Interest therefore centred on the possibility that the traffic noise level at the exposed areas of Studio 9 wall might be lower than that measured at ground level, because of the greater distance of the walls from the traffic compared with the point of measurement, and also because of screening effects which might be produced by other parts of the building. Use was therefore made of a 1:100 scale architects' model of the proposed building (constructed from cardboard by Richard McKinder of Finchley, London: see Section 2 and Fig. 4), and tests were carried out at the scale frequency of 6.3 kHz to examine this possibility. The practical techniques that were adopted in this work are the subject of this Report: the result of the tests is also given, together with the implications that this result had on the type of structure required for the exposed studio walls. Theoretical considerations of the work are presented in a companion Report[2].

2. MODELLING TECHNIQUES

In carrying out acoustic tests using scale models, certain precautions have to be taken in order to ensure a meaningful result. Considerable experience[3-6] exists in modelling the interior of large enclosures, with the objective of determining, and if possible optimizing, their acoustic properties before they are constructed. Although in principle it would have been possible to adopt the same line of approach in the present case, it would then have been necessary to model the interior acoustic properties of Studio 9 and also the sound transmission properties of the walls exposed to traffic noise, as well as the ambient noise sound field itself, at least over the frequency range under consideration. Modelling the interior of Studio 9 would have been feasible, using known techniques, and the provision of a representative sound field at the appropriate scale frequency was required in any case: the problems associated with this latter requirement have been discussed elsewhere[2]. Relatively little experience was available, however, in modelling the transmission of a partition at scale frequency, and extensive work would have been required in this field to make enough data available for carrying out scale model tests reliably. It would for example have been necessary to model not only the materials to be used to construct the leaves of the partition, but also the detailed construction of the building, in order that panel resonances, increases in transmission as a result of "coincidence effects"[7], etc. would be properly represented at the scale frequency. In view of these difficulties, a simpler approach was adopted in the present case, and (as mentioned in Section 1), use was made of a 100:1 scale model (Fig. 4). This contained reasonably accurate scale details of the external appearance of the building down to dimensions small compared with the sound wavelengths under consideration (around 55 mm on the model, corresponding to 5.5 m at full scale). The material (cardboard) used in the construction of the model could not be taken as representative of the materials to be used in the final building as far as sound transmission was concerned, but its sound reflective properties at the scale frequency of 6.3 kHz adequately resembled those of the building materials at full scale (see below).

It is clear that the position of the sound source in relation to the model is important. Fig. 5, for example, shows a view of the model taken as if looking up at the north-east wall of the studio from a position in the road outside the building: it can be seen by comparing Fig. 5 with Fig. 2 that the exposed portion of the wall is obscured by the projecting lower part of the building. To assist in the correct placing of the sound source, an outline of the road and pavement layout was drawn on the base-plate of the model. As it is quite possible that the road layout may be altered during the life-time of the building, sound source positions which correspond to the present position of the pavement were not excluded. Reflection of sound from adjacent buildings is an important consideration[2], and these buildings were therefore modelled using flat sheets of cardboard, as can be seen in Fig. 4 (compare with Fig. 3).

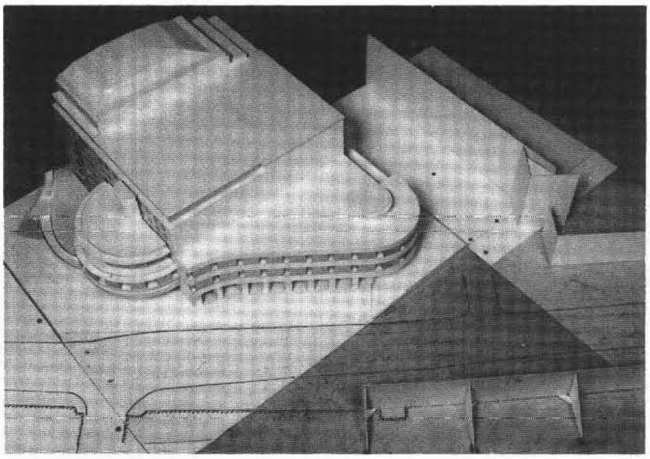
Fig. 4 - Illustration of 100:1 scale model used for the tests.

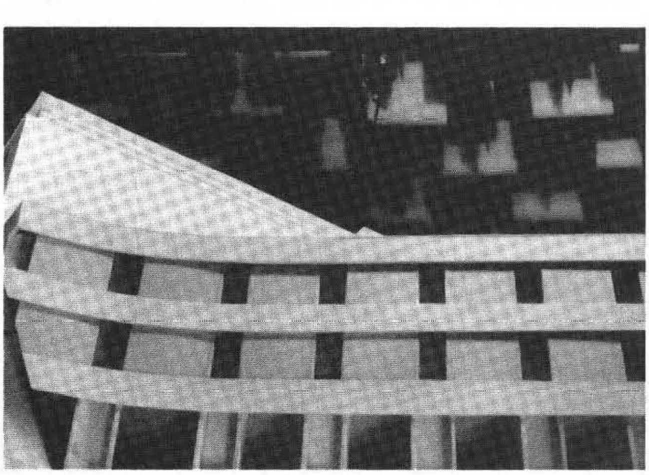
Fig. 5 - View of model showing screening of exposed wall surface.

A further difficulty which is sometimes encountered in scale modelling is caused by the existence of "boundary effects" in the layer of air immediately in front of a reflecting surface[8]. These effects relate to energy loss due to the internal friction (viscosity) of air, and the transfer of heat from compressions or rarefactions in the sound field to the surface, and have the effect of making the acoustic impedance at the boundary frequency-dependent. The conditions for reflection of sound at the surface are therefore different at the "full-scale" and "model" frequencies, with the result that measurements made using the model do not accurately portray the effects that would occur at full scale. For a 100:1 scale model these effects are not important for "full-scale" frequencies below about 200 Hz, and may be ignored in the present work: they should be borne in mind, however, when considering higher frequencies.

3. EXPERIMENTAL DETAILS OF TEST

3.1 Construction of sound source

In the modelling work, the reflection of sound from neighbouring buildings was taken into account, and in addition measurements were taken both at road level and at various heights above it. In order to excite the sound reflections appropriately, and also to give the correct weight to the measurements made at different heights, the directional properties of the sound source used in the modelling work had to represent those of the "full-scale" sources (road vehicles). At the low frequencies under consideration, the basic radiator of noise in the latter case (the end of the exhaust pipe of a vehicle) is so small compared with the sound wavelength that it may be regarded as an omnidirectional source: thus the source used in the modelling work also required to be omnidirectional. In practice, however, a source which is omnidirectional in "half-space" (i.e. to one side of a plane, representing in this case ground level) at the scale frequency of 6.3 kHz is hard to achieve. The main problems associated with a conventional loudspeaker unit are the size of the radiating area, which is a significant fraction of a wavelength and will therefore have directional properties, and the presence of the drive assembly (e.g. the magnet and voice coil) which would inevitably place the radiating area above general "ground level" (unless the unit is inset into the baseplate of the model) as well as itself giving rise to further non-uniformity of radiation. Insetting the sound source in the base-plate of the model, so as to eliminate the effects of the drive assembly, was considered impracticable because of the need to move the sound source during the tests in order to maximize the noise level in the region of the exposed wall areas (see Section 3.3). The design finally chosen for the sound source consisted of a small pressure-driven high-frequency loudspeaker unit (L, Fig. 6), coupled by means of a short tube (T) approximately 25 mm in diameter to a longer flexible tube (P) 6 mm in diameter. This latter tube turned through a right-angle at its open end, which was flush with (and at the centre of) a "ground-plane" (G) consisting of a square of cardboard of side 100 mm. The ground-plane was held parallel with the base-plate of the model and 8 mm from it (to give clearance for the pipe). Intrinsically this arrangement was very inefficient and it was found that significant radiation occurred from the exterior of the unit itself: to control this the complete unit was covered by a layer of modelling clay (D in Fig. 6), and the unit was placed in a position remote from the measurement site (usually under the table supporting the model). The unit was driven with a signal consisting of random noise, band-limited using a third-octave filter having a nominal centre frequency of 6.3 kHz[2].

The horizontal polar diagram of the arrangement described above was uniform to within ± 1dB. The vertical polar diagram (Fig. 7) was however not so uniform, showing minima between about 12° and 24°, and maxima around 50°-54°, depending on the orientation of the vertical plane in which the measurements were made. Calibration of signal level (see Section 3.3) was always carried out with the microphone in a direction corresponding to the point C in Fig. 7, while the measurements involved angles of elevation between about 6° and 42° (lines A and B). Errors of between −1 dB and 2.5 dB, at most, are therefore likely to be produced by the non-uniform vertical polar diagram of the source. On average the error is likely to be less than about 1 dB and this has been disregarded in the present work, although the effect of the minimum in the vertical polar diagram has been noted where appropriate (see Section 4.3).

Although the measurement technique only involved comparisons of sound pressure levels, and

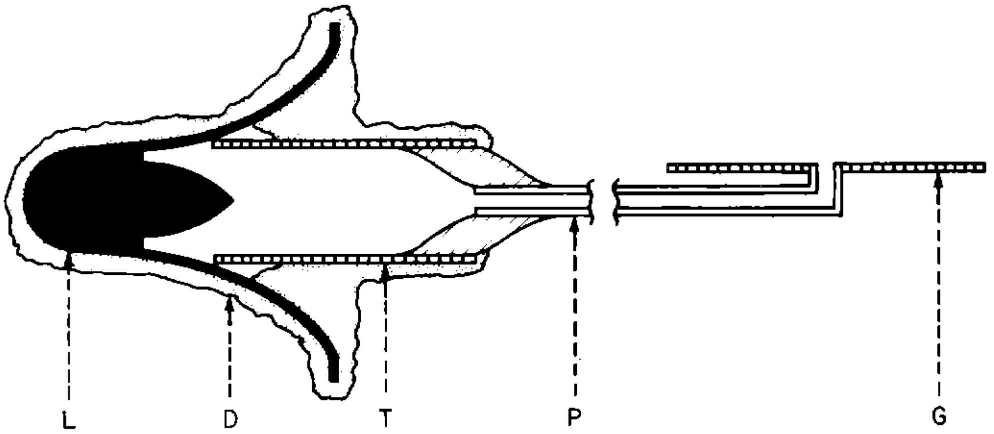

Fig. 6
Diagram of sound-source construction.

therefore did not require the absolute radiated signal level to be accurately known (so long as it remained constant during the tests), it was nevertheless found convenient to set the sound source input signal to a standard level for all the tests. This procedure ensured that the sound source was always run at a level which gave sound pressure level values high compared with the background noise, while at the same time maintaining the signal at a level that the loudspeaker unit could accept for extended periods.

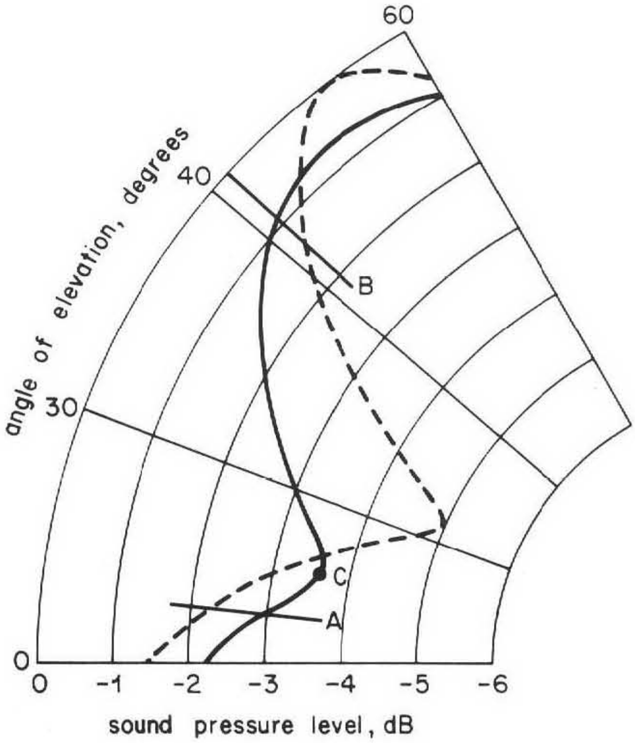

Fig. 7 - Measured vertical polar diagrams of sound source.

—— In plane passing through centres of opposite sides of ground plane.

- - - - In plane passing through opposite corners of ground plane.

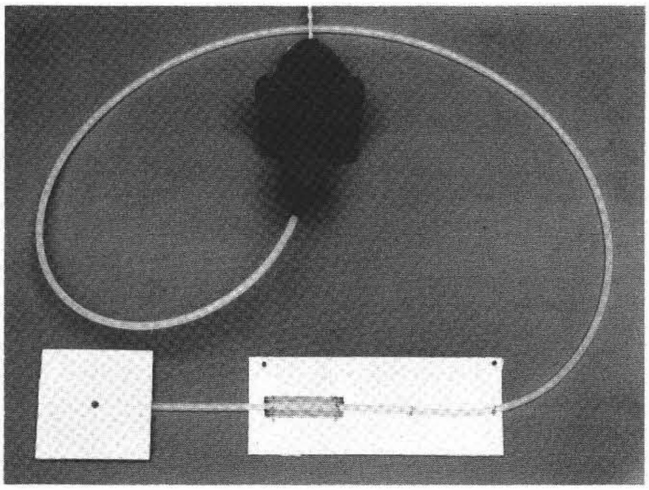

Fig. 8 - Illustration of sound source.

Fig. 8 illustrates the sound source, and this can also be seen in use in Fig. 12. The square "ground-plane" can be seen in the lower left-hand corner of Fig. 8: the sound-source position was stabilized by attaching the flexible tube to another sheet of cardboard (to the right of the ground-plane in Fig. 8) which could be held down to the base-plate of the model with weights.

3.2 Microphone and signal-measurement chain

A miniature microphone was used, having face dimensions of 7 mm × 5 mm and a thickness of 2 mm: these dimensions included the head amplifier. Although in full-scale terms this represented a device of size 0.7 m × 0.5 m × 0.2 m, which is still very much larger than a practical microphone, its polar diagram was nevertheless omnidirectional at the scale frequency of 6.3 kHz with a variation of less than ± 0.5 dB with azimuth. The microphone was supported by a "stalk" about 2 mm in diameter, containing the connecting cable, from a rigid stand positioned so as to minimize sound reflection to the microphone position.

In principle, the third-octave bandpass filter inserted into the sound source signal (see Section 3.1) was sufficient to define the system bandwidth. It was however found useful to provide additional filtering in the measurement chain, principally to provide protection against low-frequency ambient noise, which was present despite the quiet environment used for the tests. This filtering took the form of an octave bandpass filter, whose characteristics did not affect the noise spectrum used during the tests.

Signal levels were measured using a meter calibrated in absolute terms for sinusoidal signals. The calibration error introduced by the use of band-limited noise was not significant as the same noise spectrum was used thoughout the tests and only comparative measurements were made. The time constant of the measuring system was not long enough to remove entirely the fluctuations in indicated level caused by the use of noise, and the minimum level change that could be observed with certainity was 0.5 dB: this degree of resolution was regarded as adequate in view of other measurement uncertainties present in the tests.

Fig. 9 shows a diagram of the complete signal chain.

3.3 Test procedure

The model was set up in an anechoic chamber, both to eliminate errors caused by reflections from room surfaces and to provide a quiet environment for the tests. A "reference surface" which modelled the conditions used in the traffic noise survey discussed in

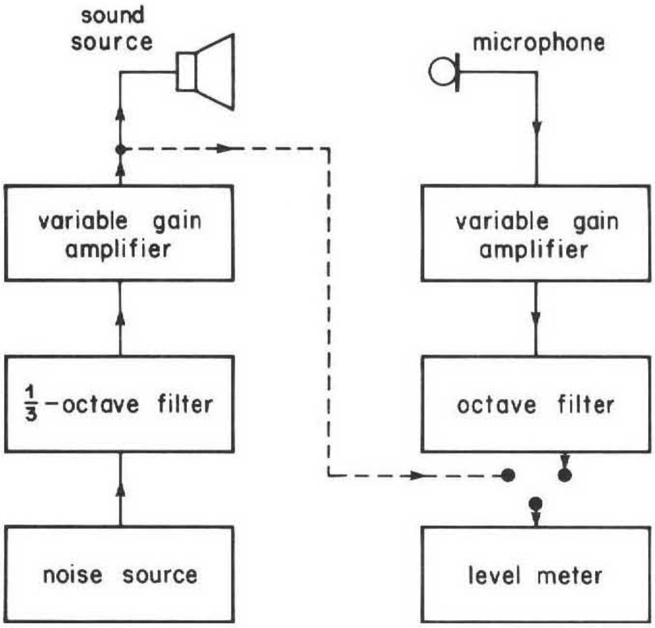

Fig. 9 - Signal chain used in tests.

Dotted line shows connection for setting sound source level.

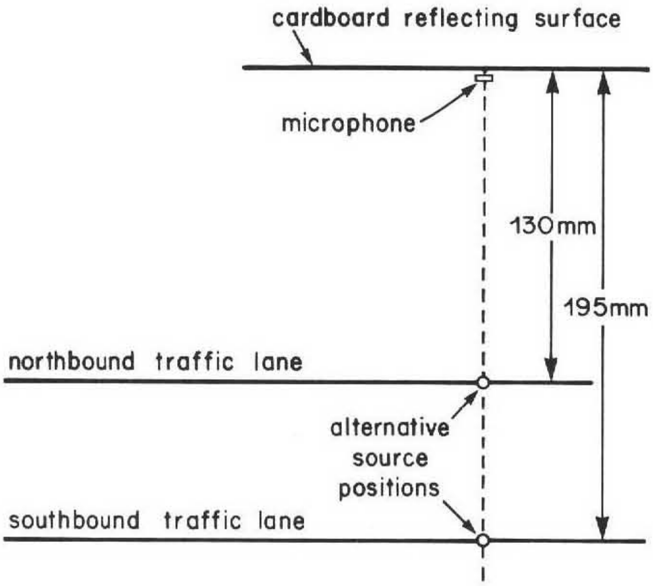

Fig. 10 - Arrangement used to model traffic noise survey conditions on a 100:1 scale.

The microphone was 40 mm above the base-plate of the arrangement, and as close to the reflecting surface as possible without actually touching it.

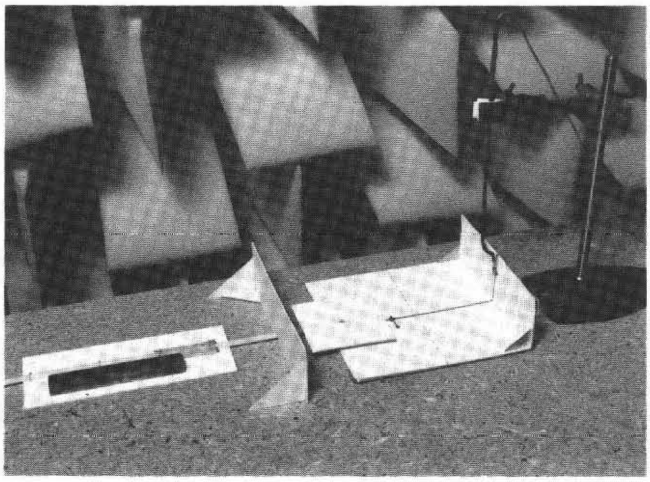

Fig. 11 - Reference surface representing conditions used in traffic noise survey.

Section 1 was also set up in a position where its presence would not affect measurements made on the model, and vice versa. This reference surface is shown in diagrammatic form in Fig. 10 and is illustrated in Fig. 11: the reflecting surface which can be seen to the left of centre in Fig. 11 modelled the wall of the London Transport tube station opposite the measurement site. The microphone was placed as close to the reference surface as possible (without actually touching it) in order to avoid errors in measured noise level caused by standing wave effects in front of the surface[2].

Noise level measurements were first made using the reference surface, with the sound source in a position representing a vehicle in the southbound lane of the road. At first sight a measurement with the source in a position corresponding to the northbound lane would seem to represent the maximum noise level that would be obtained at the test site, since this position was nearer to the reference suface and gave a noise level approximately 2.5 dB higher. There was, however, some evidence[2] to suggest that at the time of the survey the maximum recorded level in the 63 Hz 1/3-octave band may have been some 3.5 dB too low. The use of the reference noise source position giving the lower noise level reading compensates, at least to some extent, for this possibility. It may also be noted that the procedure for selecting the sound source position when making measurements on the model, described below, always resulted in the source being placed in a position corresponding to the southbound lane of the road: thus using this position again for the calibration procedure gave consistency to the tests as a whole.

Following this calibration procedure, the microphone was placed at the centre of the exposed Studio 9 wall under investigation (again so as just not to touch the wall) and the sound source was moved in the area occupied by the road (and pavement, to allow for subsequent road re-alignment) until a position giving maximum sound level at the microphone was found. The sometimes very considerable variations in noise level with sound source position were caused by interference effects between sound arriving at the measurement site both directly from the source and by way of reflections from neighbouring surfaces[2]. A more detailed measurement of sound level over the exposed wall area was then made by dividing this area into a number of equal "sub-areas" and then measuring the level at the centre of each one. As required by theory[2] the power average of these individual values was then taken. The whole procedure was repeated for the other exposed studio wall. The two power average sound pressure level values, one for each exposed wall surface, were then combined and compared with the reference-surface measurement to give a measure of the overall reduction in noise sound pressure level at the exposed wall surfaces.

Fig. 12 shows the measurements described above in progress. The sound source may be seen in the lower left-hand part of the figure, and the microphone on its "stalk" in the centre.

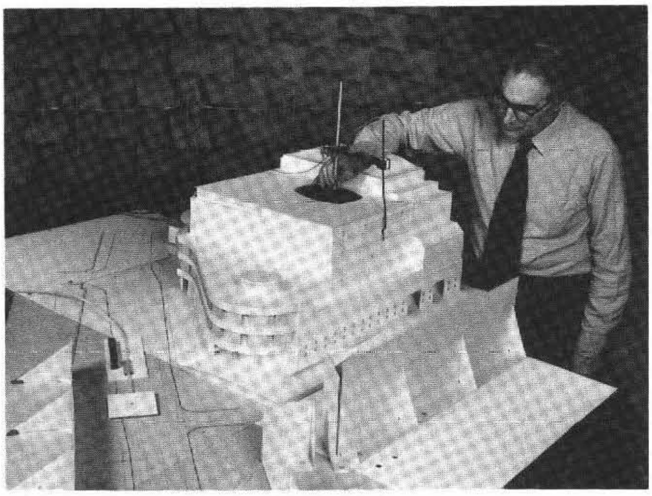

Fig. 12 - Illustration of the test procedure.

4. DISCUSSION OF TEST RESULTS

4.1 Summary of theory

The transmission loss requirement for the walls of an enclosure, where differing external (or "source") sound pressure levels exist at each of a number of panel* surfaces (themselves of differing areas), but where the transmission loss of all such panels is the same, is discussed in detail elsewhere[2]. It is shown that if the n^{th} panel has an area S_{Pn} and a (uniform†) source sound pressure p_{Sn} is present, and further that if there are N panels altogether, then

$$p_R^2 = \frac{\tau}{\bar{\alpha}_R S_R}\left(p_{S1}^2 S_{P1} + p_{S2}^2 S_{P2} + \dots + p_{SN}^2 S_{PN}\right) \tag{1}$$

where p_R is the sound pressure level in the enclosure (i.e. on the "receive" side of the panels),

τ is the transmission coefficient (the fraction of incident power) transmitted through the wall, per unit surface area,

$\bar{\alpha}$ is the mean absorption coefficient of the surfaces of the enclosure,

and S_R is the total surface area of the enclosure.

It is convenient to express the sound pressures over each panel in terms of a "datum" sound pressure p_D : thus the sound pressure at the n^{th} panel becomes

$$p_{Sn} = \Delta\, p_{Sn}\, p_D$$

where $\Delta\, p_{Sn}$ is the factor by which the sound pressure at the panel differs from the datum value.

Equation 1 can then be written in the form

$$p_R^2 = \frac{\tau}{\bar{\alpha}_R S_R} \,.\, p_D^2 \,.\, \Delta\, p_{av}^2 \,.\, S_{PO} \tag{2}$$

where

$$S_{PO} = S_{P1} + S_{P2} + \dots + S_{PN} \tag{3}$$

and

$$\Delta\, p_{av} = \left(\frac{\Delta p_{S1}^2 S_{P1} + \Delta p_{S2}^2\, S_{P2} + \dots + \Delta p_{SN}^2 S_{PN}}{S_{PO}}\right)^{1/2} \tag{4}$$

In logarithmic units Equation 2 becomes

$$L_T = L_D + \Delta L_{Sav} - L_R + 10\log_{10}\frac{S_{PO}}{\bar{\alpha}_R S_R} \quad \text{(dB)} \tag{5}$$

where L_T is the transmission loss, given by

$$L_T = 10\,\log_{10}\frac{1}{\tau} \tag{6}$$

L_D is the datum noise sound pressure level corresponding to the datum noise sound pressure p_D,

L_R is the noise sound pressure level inside the enclosure,

and $\Delta\, L_{Sav}$ is the average difference of the sound pressure levels at the panels from the datum value, calculated using Equation 4 followed by conversion into logarithmic units: thus

$$\Delta\, L_{Sav} = 20\,\log_{10}\Delta\, p_{av} \tag{7}$$

---

* In this context, an area of the wall of a building which is exposed to ambient noise may be described as one "panel", another area exposed, say, to noise of a different level a second panel, and so on.

† If the sound pressure over a panel is not uniform, the root-mean-square average value should be taken, as described in Section 3.3.

Equation 5 is more conveniently expressed as

$$L_T = \Delta L_p + 10\log_{10}\frac{S_{PO}}{\bar{\alpha}_R S_R} \text{ (dB)} \qquad (8)$$

noting that the sound pressure level difference ΔL_p is given by

$$\Delta L_p = L_D + \Delta L_{S_{av}} - L_R \text{ (dB)} \qquad (9)$$

and the panel area is taken as the sum (S_{PO}) of all the individual panel areas, as shown by Equation 3. Note that the choice of datum noise sound pressure level is arbitrary in the first instance, but once the choice has been made it must be maintained throughout the calculations.

In the present case a distinction must be made between two types of source sound field, since the data[1] used in Section 4.2 of this Report to relate sound pressure level differences across a partition to the construction of that partition was obtained using a reverberant source sound field (random incidence), while the sound field due to road traffic noise is direct in character. Assuming normal incidence, four times as much power (i.e. a factor of 6 dB) falls onto a given area of surface under direct sound field conditions, as compared with the case when a reverberant field is present[9]. To take account of this factor, Equation 8 may be written

$$L_T = \Delta L_p + C + K \text{ (dB)} \qquad (10)$$

where

$$C = 10\log_{10}\frac{S_p}{\bar{\alpha}_R S_R} \qquad (11)$$

and $K = 0$ for a reverberant source sound field,

or $K = 6$ for a direct source sound field, normal incidence being assumed.

4.2 Average sound pressure levels and wall design implications

In the following discussion, the sound pressure level measured at ground level under conditions corresponding to those used for the traffic noise survey has been taken as the "datum level" L_D in Equation 9, Section 4.1. By following the experimental procedure described in Section 3, it was found that the power average sound pressure level at each of the two exposed surfaces of Studio 9 wall was 12 dB below this datum level. The fortuitous result that the average sound pressure level reduction was found to be equal at the two surfaces makes the process of taking an overall average for the sound pressure level difference unnecessary: thus in Equation 9, $\Delta L_{S_{av}} = -12$ dB.

The implications of the reduction in traffic noise sound pressure level at the exposed Studio 9 wall surfaces may be found by considering actual sound pressure level differences between the interior and exterior of the studio in relation to the wall construction required to achieve these differences, as shown in the published data[1] mentioned in Section 1. Assuming that the transmission loss of a partition is determined only by its construction and is independent of its surface area, it can be seen from Equation 10 that

$$\Delta L_{pT} + C_T + K_T = \Delta L_{pD} + C_D + K_D \text{ (dB)}$$

or

$$\Delta L_{pT} = \Delta L_{pD} + (C_D - C_T) + (K_D - K_T) \text{ (dB)} \qquad (12)$$

where the subscript T refers to conditions in Studio 9, and the subscript D to those under which the sound pressure level differences given in the published data were measured.

The areas of the exposed parts of the North-East and North-West walls of Studio 9 are 189 m^2 and 434 m^2 respectively giving a total area of 623 m^2. Other parameters of Studio 9, together with those of a typical sound broadcasting studio, which are assumed to apply to the published data, are shown in Table 1.

Table 1
Parameters for calculating factor C in Equation 12.

Parameter	Studio 9	Typical studio, applicable to published data
Dimensions (m)	see Fig. 1	6.7 × 5.0 × 3.3
Volume (m^3)	18460	110.6
Total surface area (m^2)	4360	143.2
Transmitting panel area (m^2)	623	22.1
Reverberation time (sec)	1	0.3
Mean absorption coefficient (from Equation 13)	0.5	0.34
Factor C in Equation 12 (dB) (from Equation 11)	$C_T = -5.5$	$C_D = -3.5$

The value of absorption coefficient is based on the Eyring relationship[10]

$$T = \frac{0.163\,V}{-S\ln_e(1-\bar{\alpha})}$$

which gives

$$\overline{\alpha} = 1 - \exp \frac{-0.163\,V}{ST}$$

where V and S are the volume and surface area of the room respectively,

T is the reverberation time

and $\overline{\alpha}$ is the mean surface absorption coefficient.

From Table 1 it can be seen that

$$C_D - C_T = (-3.5) - (-5.5) = +2 \text{ dB}.$$

It was noted in Section 4.1 that in the case of transmission of sound from the exterior to the interior of a building the sound field outside the building was likely to be direct in character, with normal incidence assumed, while for measurements between two rooms (as in the case of the published data) the source sound field was reverberant (random incidence). In Equation 12, the value of K_T is therefore 6 dB and the value of K_D is zero: thus

$$K_D - K_T = -6 \text{ dB}.$$

Equation 12 therefore becomes

$$\Delta L_{pT} = \Delta L_{pD} - 4 \quad \text{(dB)} \qquad (14)$$

which shows that for a given wall structure, the sound pressure level difference obtained in Studio 9 will be 4 dB lower (i.e. 4 dB less insulation) than as indicated in the published data, or, alternatively, that for a given sound pressure level difference requirement in Studio 9, the appropriate structures shown in the published data will be those showing sound pressure level differences 4 dB or more higher than this requirement.

During the traffic noise survey mentioned in Section 1 a peak level of 107 dB was recorded in the 63 Hz third-octave band: however, a value of 100 dB can be regarded as representing a more reasonable peak level for practical purposes. Thus in Equation 9 L_D = 100 dB. The noise criterion appropriate for Studio 9 is BBC Criterion (ii)[11] relaxed by 5 dB, and this indicates that at 63 Hz the noise sound pressure level in the studio should not exceed 41 dB (i.e. L_R = 41 dB in Equation 9). On this basis (i.e. ignoring for the moment the experimentally determined value for ΔL_{Sav} of -12 dB) a 59 dB difference in sound pressure level is required between the exterior and interior of the building. From Equation 14 it can be seen that a partition construction which is shown in the published data to give a sound pressure level difference of 63 dB at 63 Hz would be suitable. Inspection of the data showed, however, that a partition giving this performance involved the use of a triple-leaf construction, with its attendant difficulties in design as already noted in Section 1. Inserting the experimentally determined value of ΔL_{Sav} in Equation 9, followed again by the use of Equation 14, indicates that a partition shown in the published data to give a sound pressure level difference of 63 − 12 = 51 dB would in fact be adequate, and inspection of the published data showed that this sound pressure level difference could be achieved by using a two-leaf wall construction. This relaxation in the specification for the exposed external walls of Studio 9 will very considerably ease the problems associated with their design and construction. The actual recommended wall design consists of two high-density brick or concrete partitions, each 327 mm thick, separated by a void 546 mm wide.

4.3 The effect of adjacent structures on sound pressure levels

Inspection of Fig. 3 shows that the North-East wall of Studio 9 faces the road, while the North-West wall faces away from it. At first sight, therefore, it seems surprising that equal traffic noise levels are present at these two walls. The reason lies in the presence of other structures which modify the propagation of sound from a source on the roadway to these walls. This is illustrated in Fig. 13, which repeats the contents of Fig. 3, but which also shows the source positions (S_{NW} and S_{NE}) used for measurements on the North-West and North-East walls respectively, as well as "rays" defining sound propagation from the sources to the edges of each wall.

In the case of the North-East wall, the direct propagation of sound is obstructed by the projecting roof (R_{NE}) of the lower part of the structure. Only the extreme top left-hand corner of this wall is exposed to sound direct from the source. In fact, this particular part of the wall corresponds to the roof void above Studio 9, rather than the body of the studio itself, and the actual studio wall therefore receives sound only by way of diffraction at the edge of the lower roof. Fig. 14 shows the projection of the roof edge from the source onto the wall (P — P) and also approximate contours of sound pressure level interpolated from the measured values. The units of sound pressure level are decibels relative to the level measured at the traffic noise survey position, as described in Section 3.3. The tendency for the sound pressure level to decrease across the wall from the top left to the bottom right corners can be clearly seen, as the wall falls further into the "shadow" of the roof. The reason for the distortion of the pattern of sound pressure distribution

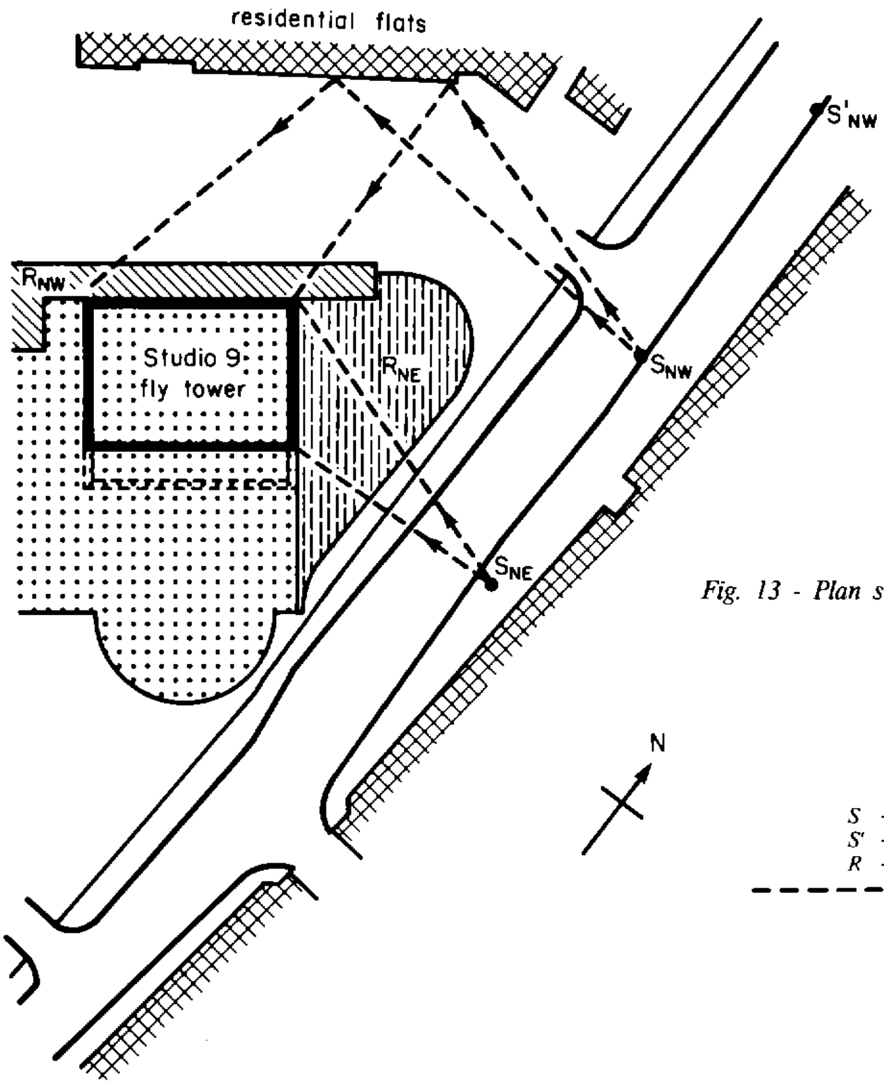

Fig. 13 - Plan showing sound source positions and sound paths.

S - Source positions used in test.
S' - Hypothetical source position (see text).
R - Roofs at lower level.
— — — — — Rays from source to wall edges.

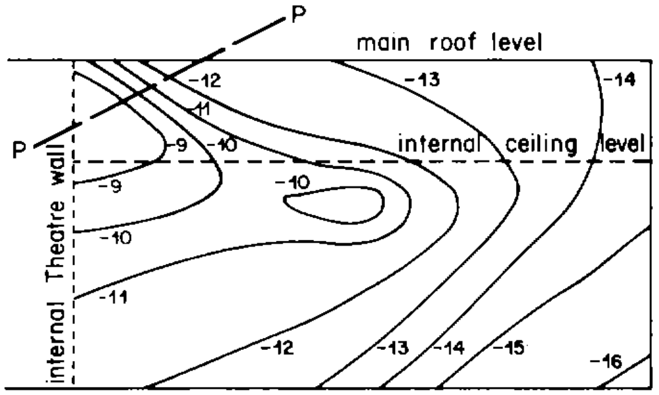

Fig. 14 - Contours of equal sound pressure level on the exposed North-East wall of Studio 9

Units are dB relative to level measured at noise survey position.

P— —P Projection of edge of lower roof onto plane of wall from source position.

on the left-hand side of the wall is not immediately apparent, but may be caused by reflection of sound by the circular structure on the roof (see Fig. 2).

The position (S_{NW}, Fig. 13) of the noise source selected for use when making measurements on the North-West wall (using the procedure described in Section 3.3) was again such that there was no direct path from the source to the wall: in this case the sound reached the wall largely by way of reflection from the block of residential flats to the North-West of the new building. This path is not greatly obstructed by the roof R_{NW}, both because of the greater distance of the sound source and also because this roof is considerably lower and narrower than roof R_{NE}. In this case, attenuation of noise at this wall is almost entirely caused by the greater path length from the source to the wall, as compared with the noise survey position. Fig. 15 shows approximate contours of sound pressure level on the wall, and the projection of the edge of the lower wall from the sound sources. The reason for the area of higher sound pressure level

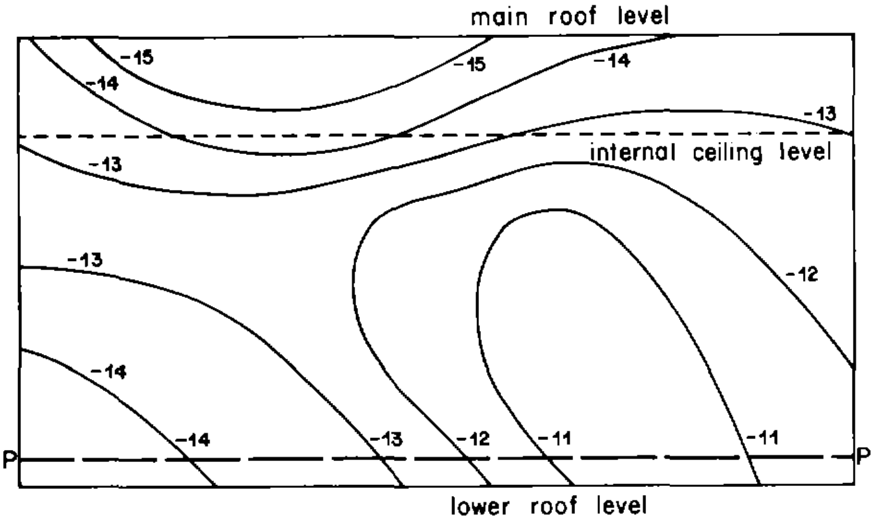

Fig. 15 - Contours of equal sound pressure level on the exposed North-West wall of Studio 9.

Units are dB relative to level measured at noise survey position.

P—— ——P Projection of edge of lower roof onto plane of wall from effective source position.

on the right-hand side of the wall is not obvious, although it could possibly have been caused by additional sound reflection from the smaller (and lower) building to the East of the main block of flats (see Fig. 4). The general decrease in sound pressure level at the top of the wall is however most likely caused by the polar diagram of the sound source (Fig. 7), which has a minimum corresponding roughly with this location.

It is instructive to consider the factors which were involved in selecting the point S_{NW} (Fig. 13) for making the detailed sound level measurements on the North-West wall, in preference to a point further to the North along the road. Remembering that sound level is measured at the centre of the wall in this selection process, a point S'_{NW} (Fig. 13) can be chosen which gives the same path length from the source to the measurement microphone as does the use of position S_{NW} (although without involving reflection of sound from the flats). Sound source positions between these two points involve shorter path lengths to the microphone than from the points themselves, and on the basis of the "inverse square" sound power law should give rise to higher measured noise levels. The principal reason for this effect not being observed in practice appears to lie in the existence of the minimum in the vertical polar diagram of the sound source, as mentioned in the previous paragraph. Changes in sound source position inevitably produce corresponding changes in the direction and angle of elevation of the microphone from the sound source, as well as changes in its distance: the overall change in measured sound level with source position therefore depends on the combined effects of these three individual factors and not simply on the "inverse-square" distance law. In the present case the conditions are such that, as the sound source is moved, the"inverse-square" level changes and those caused by the source polar diagram are of opposite sign. The resultant measured changes of sound level are therefore likely to be small (perhaps only of the same order as the measurement accuracy of ± 0.5 dB) and can be of opposite sense to those predicted by simple source-to-distance considerations. The position S_{NW} appears to represent the point at which effects caused by the source polar diagram become predominant, causing the measured sound level to fall as the source is moved further to the North, despite the decrease in source-to-microphone distance.

The effects described above serve to illustrate the complexity of the conditions existing in the "full-scale" environment, as well as the problems that may be encountered when assessing noise levels using a scale modelling technique. It is not thought that the occurrence of these effects prejudiced the general validity of the measuements, although it is likely that the detailed sound pressure distribution over the wall would have differed from that shown in Fig. 15 if a different source position had been chosen.

4.4 Additional shielding from traffic noise

It can be seen from Fig. 13 that a structure built across the gap between the new development and the buildings (residential flats) to the North-West would screen the North-West wall (and incidentally the flats) from road traffic noise. In practice there are at least two constraints on such a building: first that the Television Centre site does not (and therefore the structure cannot) extend completely across to the flats, and secondly that there will be an access road to Television Centre in this position, so that the additional building would have to have an entrance bridge or arch. Both these considerations tend to reduce the effectiveness of this building as a screen to road traffic noise. Nevertheless, a model of such a structure was constructed (Fig. 16): it was 230 mm wide with a slightly offset rectangular aperture 70 mm wide and 60 mm high, representing this entrance. It could be adjusted to be either 100 mm or 130 mm high. Sound pressure level measurements were made at the centre of the exposed North-West wall of Studio 9, the position of the sound source being adjusted for each test condition to maximize this value (although, in fact, very little change in source position was required). The results of these tests are shown in Table 2. It can be seen that this structure gives, as perhaps would be expected, a considerable reduction in noise sound pressure level at the North-West wall, which is particularly significant because this wall has the larger area of the two exposed walls by a factor of 2.3. Taking the results of Test Condition (2) in Table 2, for example, would mean that while the average reduction in noise sound pressure level at the North-East wall remained at 12 dB, that at the North-West wall now became 16.5 dB. The average value of the difference in noise sound pressure level at the exposed wall surfaces from the ground-level datum value can be found from Equations 3 and 4 (Section 4.1). In the present context these equations give

Table 2
Results of tests with additional structure

	Test condition	Reduction in sound pressure level
(1)	Structure 100 mm high	3.0 dB
(2)	Structure 130 mm high	4.5 dB
(3)	Structure 130 mm high and aperture blocked.	6.5 dB

$$\Delta p_{av} = \frac{\Delta p_{\mathrm{NE}}{}^2 \, S_{\mathrm{NE}}{}^2 + \Delta p_{\mathrm{NW}}{}^2 \, S_{\mathrm{NW}}}{S_{\mathrm{NE}} + S_{\mathrm{NW}}} \qquad (15)$$

where the subscripts denote the relevant exposed wall areas. The linear sound pressure differences can be found from the corresponding level differences: thus

$$\Delta p_{\mathrm{NE}} = 10^{-12/20} = 0.2512$$

and $\Delta p_{\mathrm{NW}} = 10^{-16.5/20} = 0.1497$

Then, since $S_{\mathrm{NE}} = 189\ \mathrm{m}^2$ and $S_{\mathrm{NW}} = 434\ \mathrm{m}^2$ (see Section 4.2), Equation 15 gives

$$\Delta p_{av} = 0.1864$$

and returning to logarithmic units using Equation 7

$$\Delta L_{Sav} = -14.5\ \mathrm{dB}$$

(to the nearest 0.5 dB). Comparing this value of ΔL_{Sav} with the value of -12 dB found when the additional structure was not in position (see Section 4.2) shows that the average sound pressure level at the exposed wall surfaces has been reduced by 2.5 dB.

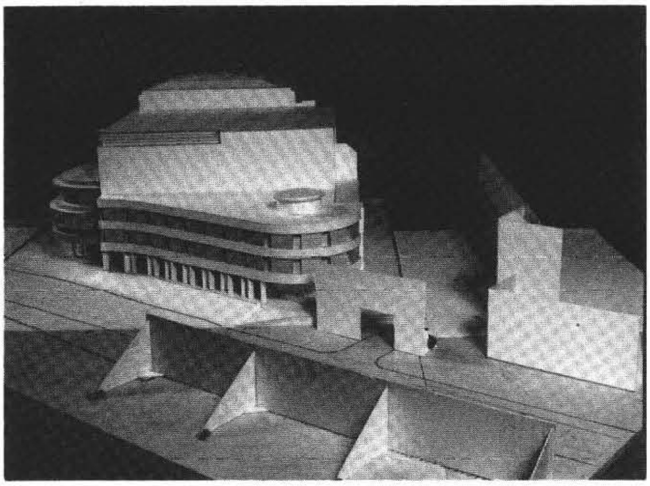

Fig. 16 - Illustration of the use of an additional screening structure.

The relaxations of the sound pressure level difference requirements of the external walls of Studio 9, which have been the subject of this Report, have referred specifically to ambient noise outside the studio caused by road traffic. It must however be remembered that such relaxations in the wall specification will lead to greater vulnerability to noise (e.g. aircraft noise) which is not subject to the screening effects that reduce the level of road traffic noise at the exposed wall surfaces. It is not thought that the use of the two-leaf rather than the three-leaf wall construction, as described in Section 4.2, will give rise to excessive noise breakthrough into Studio 9 from aircraft or other such noise, but it is felt that the transmission loss of the two-leaf wall should not be further reduced because of the presence of the "arch" structure as discussed above. This structure should be regarded simply as giving extra protection from road traffic noise. It may also be noted that the discussion throughout this Report has been in terms of traffic noise entering Studio 9 only through the exposed wall areas. In practice there may be other areas (scene dock doors, for example) through which external noise may enter the theatre and for this reason it is again not advisable to relax the wall specification unless there is a pressing need to do so. It is worth observing, in addition, that this Report has been concerned with average noise levels in the studio and that local noise levels may well be somewhat higher near the areas through which the sound is being transmitted. In the case of the elevated exposed wall areas this consideration may be significant when high-level "effects" microphones are used to capture (for example) audience reaction during a production.

5. CONCLUSIONS

The siting of a large broadcasting studio near to a road carrying heavy traffic gives rise to difficulties in specifying methods of wall construction which will give adequate sound insulation. These difficulties are made more severe when some parts of the studio wall surfaces are directly exposed to the ambient traffic noise. Mitigating factors may however exist, in that these areas may be partially protected from the traffic noise, either because of their distance from the traffic or because of the presence of other structures in the building which provide a shadowing effect.

Sound insulation difficulties are likely to be particularly severe at low frequencies, and this raises the possibility of using a scale model of the building in order to investigate these mitigating factors, while still retaining the ability to make measurements in the audio-frequency band. In the present case a 100:1 scale model was used. With the noise problem being greatest in the third-octave band centered on 63 Hz, this meant that the model work was carried out at frequencies around 6.3 kHz. Traffic noise was adequately simulated using one-third octave filtered random noise, and attention was paid to the polar diagrams of the sound source and the microphone used for the measurements. Care was needed to take into account standing-wave patterns in front of reflecting surfaces, and the use of a comparison technique in making the measurements assisted in this respect.

Several factors were found to be important when using the modelling technique. In the first place, the environment in which the building is situated requires modelling, as well as the building itself. This includes the presence of neighbouring buildings which may either reflect sound onto the area of measurement, or alternatively screen this area from the noise source. In addition, measurements should be conducted in an anechoic environment, both to eliminate spurious sound reflections and to give reasonably quiet working conditions. The model should also reproduce full-scale detail with reasonable accuracy down to dimensions of a fraction (say 1/10) of the wavelength corresponding to the noise-signal band centre frequency.

In the present work the specification of the required wall design has been achieved by comparing the required difference in sound pressure level between the interior and exterior of the studio (taking into account the noise criterion inside the building, the measured noise level outside it and the results of the tests using the scale model) with published data of sound pressure level differences found for differently-constructed walls. In using this published data, differences between the conditions used to collect the data and those applying to the studio walls themselves were taken into account. The type of noise sound field (reverberant in the case of the published data and direct in the case of the studio walls), and the differing dimensions and acoustic treatment of the "receive" room in the two cases, are relevant in this respect. It may be noted that no account was taken of possible transmission of noise into the building by paths other than through the walls under consideration, nor of any possible non-uniformity of the sound field inside the building.

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